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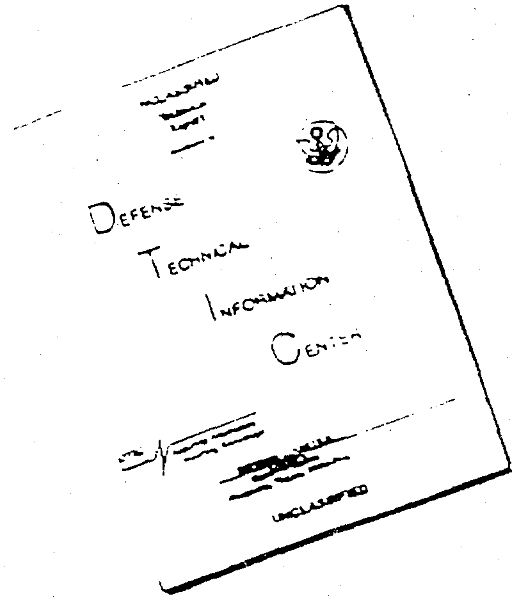

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development of a portable microcomputer system for field measurement of oculomotor parameters.

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ASPECTS OF VISUAL SEARCH ACTIVITY RELATED TO ATTENTIONAL PROCESSES AND SKILL DEVELOPMENT

Final Scientific Report, Contract F49620-79-C-0089

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Final Scientific Report   Contract F49620-79-C-0089

ASPECTS OF VISUAL SEARCH ACTIVITY RELATED TO ATTENTIONAL PROCESSES AND SKILL DEVELOPMENT

I GOAL OF PERFORMED RESEARCH

We have in previous research noted a number of measures of oculomotor activity which varied consistently as a function of accumulated fatigue. Such changes can be observed both in laboratory-based experimental tasks and in field situations. It is our impression that these alterations in oculomotor activity correspond to periods of decreased adequacy in task performance. Our primary goal in the present research has been to identify both momentary and tonic changes in alertness using oculomotor measures and to relate the eye movement-indexed periods of altered state to changes in performance.

Intermediate goals included the selection and development of a task suited to the experimental question and evaluation of several alternative measures of oculomotor function. The task selected had to be one which imposed a reasonable workload on the subject in order to develop a fatigue-like condition within a relatively brief period. If had to allow freedom of eye movement so that measures would be readily available. It was further desirable that the task provide a moment-to-moment measure of performance adequacy since our concern is with phasic as well as tonic alterations in state and behavior.

II GENERAL INTRODUCTION

A. General perspective

The oculomotor control system is exquisitely sensitive to fatigue and attentional parameters. As a finely tuned mechanical system, the oculomotor system is subject to disruption from real or incipient breakdown of cortical control. Such breakdown may be due to fatigue, boredom, lapses in attention, or physiological or pharmacological disruption of CNS function.

As a highly coordinated system of information intake, the oculomotor system reflects the efficiency of processing which is affected both by immediate information processing demands and by the total workload experienced by the operator. The overall coordination of various aspects of ocular activity depends on the task, the capability of the individual performing the task, and the current state (or capacity) of the individual. As a primary channel for information acquisition, the oculomotor system mirrors the attentional and processing strategies of the operator. Eye movement and blink responses serve on some occasions to block additional input and on other occasions, to facilitate input of specific information.

Flying an airplane is a visual task; it involves making critical decisions based on visual information. The eye, and the associated oculomotor control, is the sensing system for taking in such information. It seems inherently obvious then that it would be profitable to monitor ocular activity in an operational setting. Analysis and evaluation of this activity allow inferences concerning the adequacy of an operator's visual search activity and about state dependent alterations in the ability to input and process visual information.

Since the oculomotor system is sensitive to variations in alertness, eye movement analysis can be used to index both momentary (phasic) and tonic changes in alertness and attention. Momentary changes have been identified as performance "blocking" (Bills, 1937) and as performance "lapses" or periods of "micro-sleep" (e.g., Williams, 1967). Behavioral indicants of phasic drops in alertness include missed stimuli, occasional failures to respond to cues, and episodic degradation in general performance. Tonic changes are more analogous to the alterations labelled "fatigue", "boredom", or overload. Behaviorally, these are indexed by elevated thresholds, increased response times, and perhaps most importantly, an increased likelihood of phasic drop-outs.

Both adequacy of visual search in the alert pilot and change in the state of alertness affect performance. Most past studies of ocular activity have focused on eye position, and much progress has been made in accurately determining where the eye is directed. Comparatively little effort has been devoted to studying the nature of the eye blink and eye movements, aspects of which can tell us a great deal about changes of state which critically influence performance. Even less work has been devoted to relating eye movements to adequacy of decision-making and motor responses in complex task performance such as piloting an airplane or scanning a radar display. Because of the intimate influence of state variation on eye movement parameters, it is the later, relatively unexplored areas, which are most likely to yield useful measures and predictive tools. A number of measures which have been shown to be sensitive to time on task and pharmacological manipulation are available. Some of these are reviewed below.

B. Parameters of blinks and eye movements as indicants of alertness.

Much of our previous research has involved the use of eye movement measures to investigate information processing strategies. Tasks have ranged from tightly controlled and circumscribed laboratory tasks, to reading and simulated automobile driving, as well as on-the-road driving and helicopter piloting. Independent variables have ranged from skill or training level to pharmacological agents, such as alcohol and minor tranquilizers. We have become increasingly impressed with the effects of cumulative time-on-task and the subject's alertness level on eye movement measures. Our own experience and recent research by others suggests several measurable eye movement parameters which are informative about an individual's state of fatigue, alertness, or attention. The specific utility of several of these is elaborated below.

They include:

1. Eyeblink closure duration
2. Eyeblink patterning (timing)
3. Blink-associated saccades
4. Fixation duration
5. Saccade amplitude, velocity, and their interrelationship

1. <u>Eyeblink closure duration</u>

Much of the literature dealing with the evaluation of eyeblinks has been ably reviewed and criticized by Hall and Cusack (1972). They point out that conclusions were often based on small sample size and on samples collected under conditions in which the subject could not have been expected to be adapted to the experimental situation. In addition, results have often been contradictory. Based on large samples of blinks recorded from various populations and over several laboratory sessions, we have developed a reliable eyeblink analysis system. Our approach to blink evaluation leads to the abstraction of several descriptive parameters. One of these, blink closure duration, is sensitive to the variables of present interest.

We have found that closure duration, the time the eye remains closed during blinking, is associated with changes in alertness. The normal eyeblink is a crisp, rapid movement. The eye begins to open as soon as full lid closure is achieved. Occasional blinks are markedly longer in duration, they have longer closing and/or reopening times. A graphical comparison of these two forms of blink is presented in Figure 1.

Early observations (Kopriva, Horvath & Stern, 1971) indicated that these long closure duration blinks occurred more often after subjects had recovered (clinically) from the effects of a short-acting barbiturate than following a control period. These blinks were interspersed with other "normal" blinks.

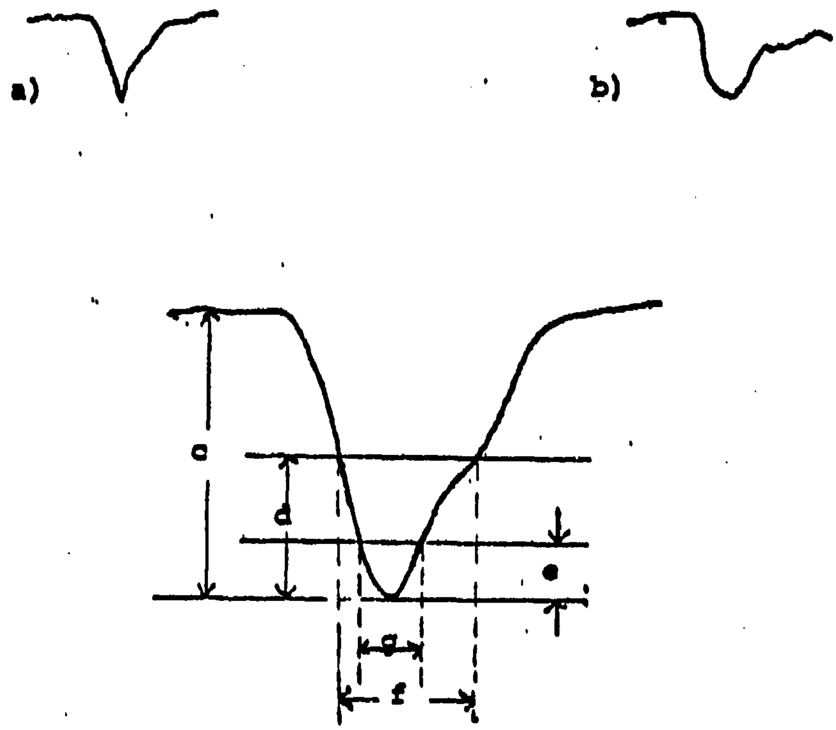

Figure 1. Scoring Eyeblinks. A typical blink (a), and long closure duration blink (b) taken from early and late in an experimental session for the same subject are shown in upper portion of the figure. The lower portion is a schematized blink illustrating: c) amplitude, d) half amplitude, e) the amplitude defining the 20% window, f) half closure duration, and g) 20% window duration.

What varied as a function of condition was not the form of the typical blink, but rather the frequency of occurrence of atypical blinks. In subsequent studies we have demonstrated similar significant increases in the incidence of long closure duration blinks for other CNS depressants (e.g., alcohol) and as a function of time on task (e.g., 40 minutes of automobile simulator driving). The intoxicated subject (BAC 75 mgm%) demonstrated more long closure durations and a more rapid development of such "abnormal" blinks as a function of time on task.

Our current procedure for detecting long closure duration blinks is illustrated in Figure 1. Basically, it consists of establishing an amplitude window defined as a proportion of total blink amplitude. The amount of time that the amplitude exceeds this window value is defined as the closure duration for that window. In preliminary work using a reaction-time task, we observed, consistent with previous results, an increase in the incidence of long closure duration blinks across a one-hour experimental session. Although this is true regardless of the window criterion size, the effect is more striking for small windows, i.e., those encompassing the time within 25% of maximal closure. Using the 20% window, for example, we find that only about 1% to 12% of all blinks during the initial 5 minutes of task performance exceed an arbitrarily established cut-off criterion of 100 msec. Midway through the hour, 3% to 25% of the blinks exceed the criterion. During the final five minutes of task performance, the range increased so that 2%-38% of all blinks satisfied this criterion for long closure duration. Having found the incidence of long closure duration blinks associated with time on task and decline in alertness, we suspect that the occurrence of such blinks is associated with drop-outs in performance--not only on tasks demonstrating the processing of visual information, but on other types of information processing tasks as well.

There is presently no systematic data on changes in median closure duration with decreasing alertness. Previous research has focused on what Hall and Cusack call "blinking blackout", the period during which the viewer is presumed to see nothing. This period is not synonymous with but includes the time during which the eyes are closed. Blinking blackout has been estimated by presenting visual stimuli at various points during the blink and determining accuracy of perception. Information on the duration of such blackouts is surprisingly sparse. The most recent published estimate we could find (Volkman, Riggs, & Moore, 1980) is 200 msec. Our investigations into the visual suppression associated with blinking suggest that this estimate is too high. The direct assessment of blink suppression requires specialized procedures somewhat removed from the tasks presumed to effect blinking duration. We have elected, therefore, to make the assumption that the blinking period is directly related to closure duration and to measure median closure duration directly. Regardless of window size, the general effect of time-on-task and related state variables is toward small increases in median duration. Although the differences are in the expected direction, they are typically so small and variable as to fail to make any significant contribution to total task performance. For example, in many tasks, variation in 20% window duration from early to late in the session is between -2 and 15 msec, with a median increase of only 2 msec. Even with 50 blinks in a five-minute period the suppression is equivalent to only .1 sec of lost viewing time.

Of greater import to adequate processing in a visual task than the time lost to blinking is eye closures which are not blinks. After cumulative experience with data reduction of large samples of blinks, we have concluded that full closure durations in excess of 150 msec do not represent blinking. Our computerized abstraction procedures were, for that reason, designed to eliminate from analysis any closure not followed within 150 msec by reopening. Since the viewer cannot input visual information with his eyes closed, these eye closures reflect either inadvertent or self-imposed "time-out" from input. It is our impression that the likelihood of these eye closures increases with time on task. They may be associated with performance errors and missed stimuli, especially in vigilance tasks. Our analysis routines have been rewritten to allow the identification of such closures from eye movement recordings.

2. <u>Eyeblink patterning (timing)</u>

Previous attempts to index visual fatigue using the blink have focused on blink rate, but interpretations of this measure are ambiguous. Luckiesh and Moss (1942) proposed blink rate as an adequate measure of visual fatigue in reading and suggested its usefulness in other tasks. Their results were, however, vigorously attacked. Carmichael and Dearborn (1947) reviewed the use of blink rate and concluded that it was a poor measure of visual fatigue. In a comprehensive review, von Cranach et al. (1949) indicated that blink rate is sensitive not only to arousal indiced by stressors and fear, developing fatigue, and similar state varwiables but also to variables, like the occurrence of head movements and large amplitude saccades, which may reflect task requirements as well as state. Too many variables other than state contribute to blink rate for it to be an adequate measure of alertness in visual information processing. It may be, however, that in relatively constant tasks, within-subject variations in blink rate do reflect state variation.

There is evidence, based on more refined measures, that blinking is influenced directly by attentional requirements of task performance. Boelhower and Brunia (1977) studied electromyographic components of the blink recorded while subjects were performing an auditory binary choice decision task. They identified two EMG components of the blink reflex. Amplitude of the early component was enhanced during task performance relative to rest while latency of the late component was increased during task performance relative to rest.

These results are important to this discussion because they demonstrate that blinking is not merely a reflex response, but is coordinated with cognitive processing at some CNS level. Review of the blink rate literature and our own observations have shown us that blink rate per se is not a sufficiently sensitive measure of changes in alertness. Measures, such as latency of blink components used by Boelhower and Brunia (1977) allow clear demonstration of a relationship between blinking and task performance relative to rest, but are not always easily related to components of task performance. Since the measurement of latency requires that responses be time-locked to triggering stimuli, this type of measure is not easily adapted to operational situations in which much of task performance may be waiting and watching. We have concentrated on a measure which can be used in operational settings: blink timing with respect to components of task performance.

Blinks are generally not randomly distributed in time but rather occur most frequently at times of reduced information processing need. We have observed that, during reading, there is a marked inhibition of blinking as a page of text is read. The degree of blink inhibition varies with the reader's interest in the text. In sharp contrast, there is a marked flurry of blinks as the reader turns from one page of text to the next. Ponder and Kennedy (1972) have reported the same phenomenon. Blink patterning is not restricted to reading. In both simulated and real automobile driving, we see an increase in blinking during periods of low visual information processing requirements. For example, blinking increases while the subject sits at an intersection waiting for the traffic light to change. In their investigation of the timing of blinks, Poulton and Gregory (1952) and Gregory (1952) found that in both visual and nonvisual tasks, blinking was inhibited during the performance of difficult task components. Similarly, in a study of 79 subjects, we found marked blink inhibition during intake of information processing necessary to task completion as compared to a comparable rest period (Stern, Oster & Newport, 1980).

Those blinks which do occur during task performance are often coordinated with other task events. Greupner (1964) reported that blinking occurs at times least disturbing to overall task performance. In automobile driving, blinks are often associated with the large saccades and head movements which accompany change of gaze from road to rear-view mirror and back. Similarly, blinks often attend the return from instrument panel scanning. It is our impression that for many subjects, this blink-task coordination begins to break down as time on task increases.

The above studies agree that blinks occur at moments opportune in terms of visual information processing requirements. Results indicate that blinking, though generally thought of as a reflex response, is coordinated with information processing load. This coordination is conducive to accurate task performance and is in that sense efficient. It is our impression that the occurrence of blinks at opportune moments occurs principally under conditions in which the subject is wide awake, alert, and highly motivated; under conditions of monotony, fatigue, etc., there is a breakdown of this coordination between blinking and aspects of visual information processing and task performance. We suspect that the analysis of blink timing and patterning within the task will provide important information about the efficiency with which a subject is processing visual information and making decisions based on that information.

3. Blink-associated saccades

Coordination between blinking and saccades would appear to minimize the time during which visual information processing is suppressed. The eye can be positioned prior to the blink so as to minimize blink closure duration.

Further, during a blink the eye may be repositioned to preclude the necessity of additional saccades immediately subsequent to the blink. In alert, well-motivated subjects, there is often an association of blinks with saccadic eye movement.

We have observed, in operational as well as laboratory situations, that many subjects demonstrate a specific pattern of ocular activity preceding the blink. A saccadic eye movement shifted eye position to the lower quadrant of the visual field. Shifting eye position to the lower area of the visual field is invariably accompanied by a partial closing of the eyelids. A blink from a position of partial lid closure should take less time to complete than one started with the eyes fully open. Since the viewer's vision is obscured during a major portion of the blink, reducing blink duration reduces the time vision is obscured.

During saccadic movement and the periods immediately preceding and following a saccade, information abstraction is compromised (Matin, 1974; Stern & Sanders, 1980). Blinking also is associated with a temporary blocking of visual input. Making a saccade during a blink is thus efficient in that it reduces the total time during which visual input is not possible. Saccades in the horizontal plane can be detected from electrooculographic records and we have observed that they frequently do occur in conjunction with an eyeblink. Vertical saccades are obscured by the larger signal generated by the blink itself. The occurrence of eye repositioning in the vertical plane can be inferred, however, by noting differences in eye position following a blink. During visual search, eye position following a blink is consistently different from eye position preceding a blink in both vertical and horizontal planes. Presumably the viewer positions the eye during the blink so that when vision is restored he will be looking at the target. By obviating the need for an additional saccade to reposition the eye after the blink, and the concomitant saccadic suppression, the time that vision is obscured is reduced.

The pattern of saccadic movement before and during the blink reduces the time vision is obscured by reducing the time for blink execution, the period of blink and saccadic suppression, and the need for an additional saccade to change eye position after the blink. In this sense it is efficient. It is our impression that this efficient coupling of saccades and eyeblinks is affected by variables associated with decrements in performance like time on task and motivation.

4. Fixation duration (micro-sleep)

It is well-documented that fixation pause duration, i.e., the amount of time the eyes dwell on a particular aspect of a visual display, is a function of the task (Fisher, 1974; Gould, 1973). Moreover, moment-by-moment analyses of eye movements reveal variation in the length of the fixation pause related to cognitive processing. It is reasonable to assume that unusually long fixation durations reflect periods of nonprocessing due to loss of alertness. Specifically, unduly long fixation pauses may reflect drop-outs in performance. Such long fixation pauses could mean either that the viewer is spending more time sampling a very restricted aspect of the visual display or that he is simply "staring" at the display without necessarily doing much seeing. Since the type of task will affect fixation duration, the duration indicating staring or drop-outs in performance as opposed to detailed visual analysis will vary from task to task. Our cumulative experience with fixation pause durations recorded during reading indicates that fixation pauses in excess of 400 msec are indicative of staring or nonreading (Under nonreading we would include task relevant behavior such as thinking about the text just read.). In the driver simulator task, we have used 2 sec or greater as an indicant of unusually long pause durations.

Several results have suggested that an unduly long fixation duration is indicative of decline in alertness and/or momentary lapses in attention.

We have found that the incidence of long durations increases with time on task and with ingestion of CNS depressant drugs like alcohol. Moreover, such lapses do not occur at random during task performance. In reading, exceedingly long fixation pauses are usually the last pause on a line of text or the first pause on a line of text. Long duration fixations also occur at predictable times in simulated helicopter flying. Specifically, Stave (1977) found lapses in performance to be significantly correlated ($r = 0.87$) with subjective ratings of fatigue.

5. Saccade amplitude, velocity, and their interrelationship.

Several parameters of saccades, the quick jumps of the eye to change eye position, are sensitive to organismic states of alertness. Among these, saccade amplitude has been used as an indicant of changes in attention to aspects of the environment. Cedar (1977) recorded eye movements during simulated automobile driving and found that traffic flow conditions significantly affected saccade amplitude. As driving stress increased, the number of large amplitude eye movements (greater than 9.5°) significantly decreased. Time-on-task also influences the frequency of large amplitude saccades. We (Troy, Chen & Stern, 1972) have demonstrated that in helicopter pilots flying a relatively simple 45-minute mission there is a significant decrease in large amplitude saccades between early and late portions of the flight. We interpreted these results as suggesting that the pilot spends less time looking for "targets of opportunity" (places to land in an emergency, important aspects of terrain, etc.), as a function of time on task. Similar results were obtained in the automobile simulator. The frequency of large amplitude saccades decreased during a 40-minute driving task. Further, low to moderate doses of alcohol increased the effect; the frequency of such saccades was lower and the decrease more rapid under conditions of intoxication.

Velocity of the saccadic movement has also been investigated in several laboratories. We (Stern, Bremer & McClure, 1974) as well as Gentles and Llwellyn-Thomas (1971) and Aschoff (1964), have demonstrated significant decrements in the peak velocity of large (10-20°) saccades after ingestion of minor tranquilizers (e.g., librium and valium). Recent data from our laboratory demonstrate that this phenomenon is not unique to large amplitude saccades but occurs in smaller amplitude saccades as well.

We have studied both saccade amplitude and velocity and find a combination of the two measures to be most useful. The maximum velocity of eye rotation during the execution of a saccade is dependent upon the distance the eye has to travel. For saccades ranging from a 5° to 20° excursion the relationship between peak velocity and saccade amplitude is essentially linear (Oster & Stern, 1979). We have demonstrated that time-on-task and "state of the organism" have a significant effect on this relationship. We have consistently found, for example, that, as a function of time-on-task, the slope of the regression line describing linear amplitude-velocity relationship decreases.

Data from one recent study illustrates the sensitivity of the saccade amplitude-velocity relationship to both time-on-task and change of state effects. The study involved participants for four one-hour experimental sessions. During each session, subjects read from Haley's Roots and after 45 min. of reading were required to answer questions regarding the text they had read. In sessions 2, 3, and 4 they were required to drink a sufficient quantity of alcoholic beverage to bring BAC level to 0, .35, or .70 mgm%. Order of level of BAC used was randomized over sessions. Eye movement data from an early, middle and final segment of reading were analyzed.

The correlation between saccade amplitude and velocity generally averaged above 0.70. Under conditions of inebriation, the slope of the regression line is significantly reduced ($p < .0005$). A similar effect is found for time on task ($p < .002$). We also found the coefficient of correlation (arc sine transformed) is significantly reduced by both alcohol ($p < .002$) and time on task ($p < .028$).

The advantages of utilizing the correlation between amplitude and velocity over amplitude, duration, or peak velocity alone are twofold. Change in amplitude might reflect changing cognitive processes or strategy of the observer as well as change in state. The observer may simply decide to search a restricted area of the display. Interpretation of the relationship between amplitude and velocity is less ambiguous. The second advantage is that the measure is ideal for determining deviations from the alert state. A relatively simple system could be developed which calculates the regression equation under conditions of optimal alertness and then compares successive data points to that equation and determines the number of saccade velocities falling significantly below the predicted velocity.

6. Utility of eye movement measures.

We have, in previous research, consistently noted that the oculomotor measures outlined above are affected by variables such as attentiveness and alertness. We believe that they can be used effectively to identify variations in such states, perhaps more adequately than direct measures of performance outcome. One superiority of oculomotor parameters is that they are sensitive to momentary changes (lapses, drop-outs), as well as tonic changes in state. Further, oculomotor measures, unlike outcome measures, can provide evidence of change of state in the absence of response to specific stimuli. A change in blink duration can be used to identify declining alertness though the subject is merely watching, responding to no specific stimulus. Outcome measures can be collected only when specific response to specific stimuli is made a sufficient number of times to yield reliable error rates.

Since operation of complex instrumentation involves periods of scanning and anticipation, measurement of eye movement parameters which can be used to assess change of state during these periods, is more useful than measures of performance outcomes. Third, performance measures are, of necessity, available only after-the-fact. In an operational setting, it would be of obvious utility to predict performance decrements before they actually occur. We believe that oculomotor indices of state will be predictive of performance degradation. Finally, it is our belief that defining periods during which one can expect decrements in performance on the basis of the proposed ocular measures may be a sensitive and useful approach since such measures can be obtained under operational as well as laboratory conditions.

Although all of the measures described above could be utilized as indexing variables, we have elected to concentrate out initial effort on the blink and blink-related measures. The reasons for this are primarily pragmatic. First, data reduction routines for the detailed kind of analysis required in the present research could be readily developed from existing software. Second, eyeblinks occur in all situations, and selection of aspects of blinking as the primary oculomotor measure allowed greater flexibility in the selection of an appropriate task. An immediate concentration on aspects of saccadic motion would have required a task, the successful performance of which demanded horizontal scanning. Such tasks are contemplated and subsequent research will consequently include examination of all the measures detailed above. The present report, however, is restricted to consideration of blink parameters as related to task performance.

C. Fractionating Reaction Time

As stated earlier, our major objective is to identify changes of state and to determine how they affect components of task performance. In the previous section we documented how parameters of recorded eye movements can be used to identify changes in state. In this section we will describe how we go about the process of distinguishing decision making and motor components in reaction time tasks involving visual stimuli and manual responses. Fractionating reaction time (RT) is useful in assessing whether reduced alertness differentially affects the time it takes to make decisions based on visual information and the time it takes to execute those decisions, once made.

In several previous studies we have fractionated RT to visual stimuli using a series of tasks in which a primarily perceptual-cognitive and a primarily motor response could be measured. In these studies subjects were instructed to make an appropriate (choice-) reaction response as rapidly as possible following stimulus onset, and to return to the starting position immediately after stimulus termination. Several components of the response were abstracted on each trial. Decision time, the perceptual-cognitive component of RT, was the time between light onset (or offset) and button release. Transit time, the motor component of RT, was the time between contact release and contact of the next switch, i.e., the time it took to move the finger from one button to the next. Decision and transit time components were measured for both forward movement from the start to target positions and for return movements from target to start positions. There were thus measures of RT under four conditions: decision time forward (DTF), transit time forward (TTR), decision time return (DTR), and transit time return (TTR).

To provide checks on the validity of our measure of perceptual and motor components of RT, we have: a) manipulated the complexity of a visuo-spatial task and b) required both left and right hand responses. Our reasoning was that if decision and transit time reflect perceptual-cognitive and motor functions, respectively, increasing the complexity of the decision about which hand to move in response to a specific light should affect decision time, but have minimal effects on transit time. Second, a faster left hand response was anticipated for the perceptual (DTF) component of RT because there is a demonstrated right hemisphere advantage for visual perception tasks and because the right hemisphere controls fine motor responses on the left side of the body. A faster right hand response was expected for transit time, the motor component of RT, because faster motor response is generally associated with moving the dominant or preferred hand.

We also entertained different expectations for the forward and return movements. Instructions regarding stimulus-response contingencies were manipulated so that the decisions required preparatory to the forward movement were more complex than those required prior to the return movement. Before making the forward movement the subject had, in some conditions, to decide which hand to move, depending on which light was illuminated; in return movements the subject had invariably to return whichever hand was away from the start position back to that position. DTF was, then, a measure of more complex perceptual-cognitive response than DTR. Task complexity was expected to affect DTF more than DTR. No such differential effect of task complexity was expected for TTF and TTR.

The results of several experiments (Stern, Oster & Newport, 1979, 1980) generally confirm that our measures of decision time and transit time do reflect perceptual-cognitive and motor components of RT to visually presented stimuli. First, decision time was generally more than twice as long as transit time, as would be expected of the time necessary to arrive at a decision as compared to the time necessary to enact that decision (motor time). Second, as expected, task complexity increased decision time aspects of DTF but had comparatively minimal effects on transit time and DTR. Task complexity accounted for 45% of the variance in DTF, as compared to 5% for DTR, and 1% for both TTF and TTR. Third, there was a significant hand by decision vs. transit time interaction. Decision times were more rapid with the left hand response and transit times were faster for right hand responses. However, this result was significant only for the forward movement, i.e., DTF and TTF.

III. RESEARCH CONDUCTED

The completed research was conducted in four phases. The first phase involved the selection of a general version of a visual information-processing task and the development of a hardware/software system for task presentation. The second step was a preliminary study comparing the effectiveness of several variations of the task, evaluating oculomotor changes, performance variation, and subject's subjective report. In phase three a formal study was conducted. The final phase involved the reduction of the acquired data. Concommitant with this effort, software development of an analysis system for saccade amplitude-velocity measures continued. Further, a feasibility study was conducted to assess the possible development of a portable microcomputer system for field measurement of oculomotor parameters.

A. Task Selection and Software Development

Minimal requirements for an experimental task were that it: 1) yield frequent measures of performance adequacy; 2) be primarily visual in nature; 3) provide oculomotor measures; and 4) be subject to fatigue, or fatigue-like, state changes. It was further desirable that the task: 5) correspond, at least theoretically to real-life field situations; 6) involve both memory and decision-making in information processing; and 7) not require extensive periods of training.

We designed an information-processing reaction-time task which satisfied most of the above criteria. A continuing sequence of alphabetical stimuli were presented on a screen. Each stimulus letter occasioned a response. The subject was required to compare the letter with the previously presented letter, make some categorical decision based on the relationship between the two letters and perform a choice-reaction-task response based on that decision. This constitutes a frequently elicited behavioral response yielding performance indicants based both on error measures and on measures of fractionated RT. It is a visual task requiring memory for previous stimuli as well as a decision regarding the current stimulus.

Clearly, there are a large number of possible decision rules which could be based on the sequential relationship between letters. The program developed to control the experimental sessions was built to incorporate several of these possibilities. The variations included were: CASE, upper vs. lower;

alphabetical SEQUENCE, sequential letters either immediately adjacent in the alphabet or not; and CATEGORY, vowel or consonant. The latter two could be combined with the first to generate more difficult tasks.

The basic hardware consisted of a PDP-11/40 computer with its associated peripherals and "in-house" constructed special devices. Software and hardware development specific to this research progressed in an integrated fashion. On entering the experimental program (NUALPH), the operator selected the task parameters. At initialization the value of the "previous stimulus was set to the upper-case letter "A", the interstimulus interval counter was set to 3 sec, and the clock started at a 10 msec tick interval. For the first, and each subsequent trial, the program then progressed through a series of calls to a random number generator routine. If, for example, the task variation, CASE, had been selected, a random letter was picked, then a random probability value was selected. If this value exceeded that specified by the operator as the percent of occasions on which case should change, then the case of the randomly selected letter was made the same as that of the previously presented letter. Otherwise, the case was altered. Similar procedures were followed for the other task variations. After the generation of the character, the random number generator was again addressed, this time to select a stimulus duration from a rectangular distribution of possible durations within limits set by DATA statements in the program. The X and Y coordinates of the screen location for the next stimulus were determined in a similar manner. The program then looped until the conclusion of the interstimulus interval.

At that time the ASCII code of the generated signal was transmitted via a RS232 interface to a Magnavox plasma display terminal located in the nearby experimental room. A plasma terminal was selected rather than a traditional display scope because it provides more accurate control of the exact time of stimulus occurrance. The zero persistence of the image on the type of display further allows accurate determination of latency of the response to stimulus offset. Three additional events occurred coincident with stimulus transmission. 1) Latency and interval times were reset. 2) The ASCII code for actual character presented was stored in an array for subsequent listing. 3) A coded indication of stimulus status (in or out of SEQUENCE, change in CASE, and/or change of CATEGORY) was placed on the digital output lines of the computer. The digital signal was used to activate a telephone frequency encoder unit which generated those tones corresponding to the digital signal. These frequency encoded numbers were then recorded on a standard audio channel of a tape recorder to be used in subsequent off-line data analyses.

The program then randomly selected the duration of the next interstimulus interval and entered a wait loop until the conclusion of the stimulus duration interval. At that time the screen was erased, interval and latency counters reset, and the digital output lines cleared. The program looped through this entire procedure for an operator-selected number of trials and then printed the accumulated data for that trial block on a line printer.

Choice responses were recorded from a three position touch pad panel situated in front of the display terminal (see Figure 2). A piece of conductive foam was attached both to the subject's wrist and to the grounding circuit of the response panel such that when the subject touched any of the response pads a circuit was completed. The panel was wired so that any change in state (i.e., either making or breaking contact with a touch pad) generated an interrupt signal on the digital input lines to the computer. Separate bits on the digital lines corresponded to each of the individual touch pads. The response panel also ouptut a d.c. voltage, the level of which is proportional to the numerical code of the touch pad contacted. This d.c. signal was fed directly to the tape recorder.

a)

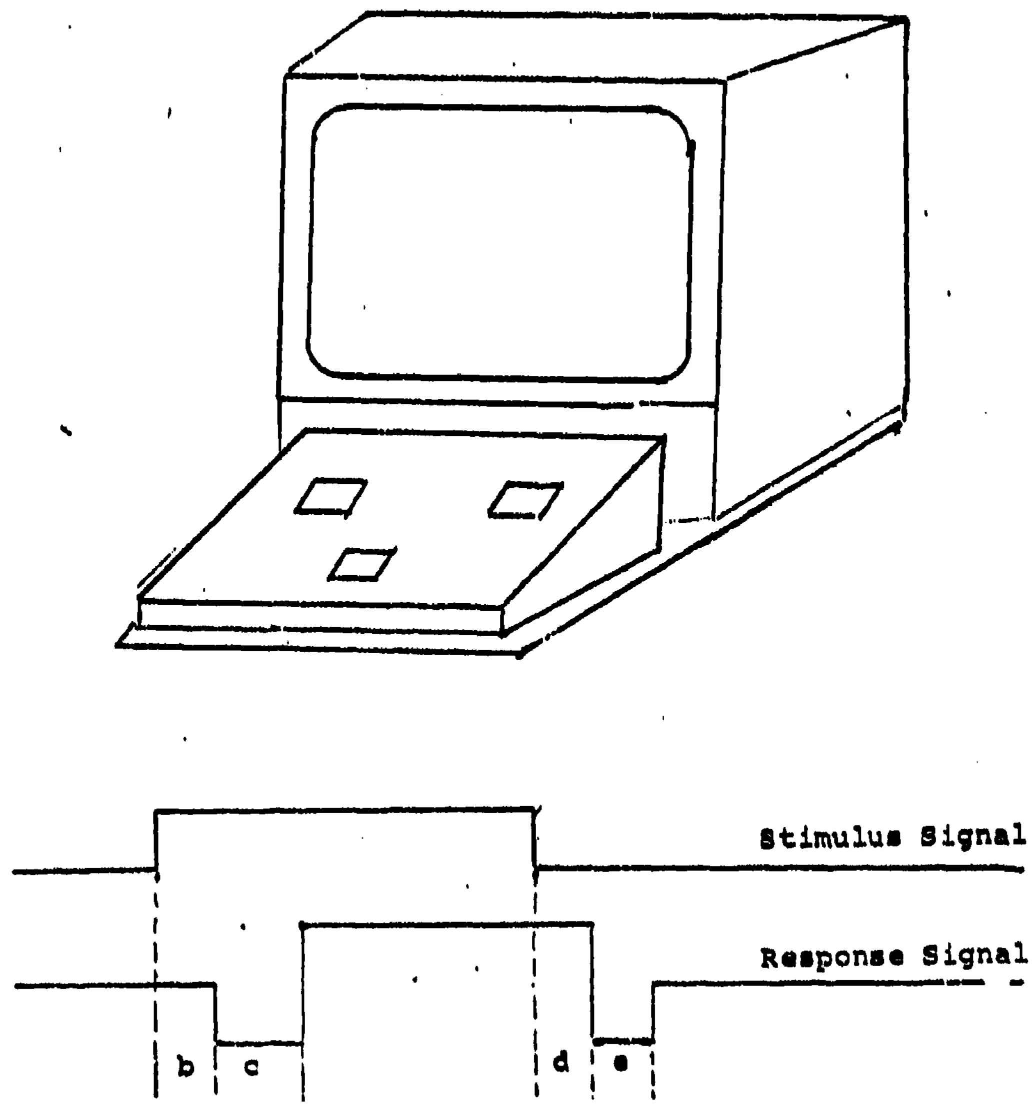

Figure 2. Task Apparatus. The equipment consists of a) a video monitor, a touch-pad response panel consisting of a proximal "home" pad and two distal choice pads for the primary task. The lower portion of the figure schematically illustrates the four RT components of the primary task; b) DTF, time between stimulus onset and release of the home pad; c) TTF, time the finger is off the key; d) DTR, time between stimulus offset and choice pad release; and e) TTR, movement time from choice to home pad.

On receipt of a digital input, the program executed a software interrupt. The numerical code for the response and the contents of the latency counter were moved into the print array. This information was thus included in the printout after each trial block.

The complete instrumentation set-up, illustrated in figure 3, included a dual eye movement amplifier. These circuits amplified the electrooculographic signals (picked up by appropriately located Beckman biopotential electrodes) prior to transmitting to the tape recorder. Horizontal and vertical EOG were recorded separately.

The NUALPH program generated stimuli and monitored the behavioral response. Reaction-time measures (both time and error) were immediately available from the real-time, on-line analysis. A second program was developed for off-line analysis of the tape recorded data. This reduction program converted four tape recorded channels of data from analogue to digital format. Successive 10 second frames of this data were displayed in graphic form at the computer terminal. Reduction routines for three of these channels were incorporated into the program. They were: 1) stimulus; 2) choice response; and 3) vertical EOG. The vertical EOG was analyzed for the occurrence of blinks and characteristics of each blink, time of occurrence, amplitude, half-closure duration, and window duration (as defined in section II.B.1 of this report) were abstracted.

B. <u>Preliminary Studies</u>

Eight subjects, primarily laboratory personnel, were run for varying time periods to assess the effectiveness of the task. All task variations and several complex decision rules involving combinations of task variations were employed. The first several subject runs were analyzed only with respect to the performance measure. It rapidly became apparent that the more complex rules were too difficult to master. Using a complex rule, such as: (press left if case has changed <u>and</u> the letter is not in alphabetical sequence) <u>or</u> (if the case

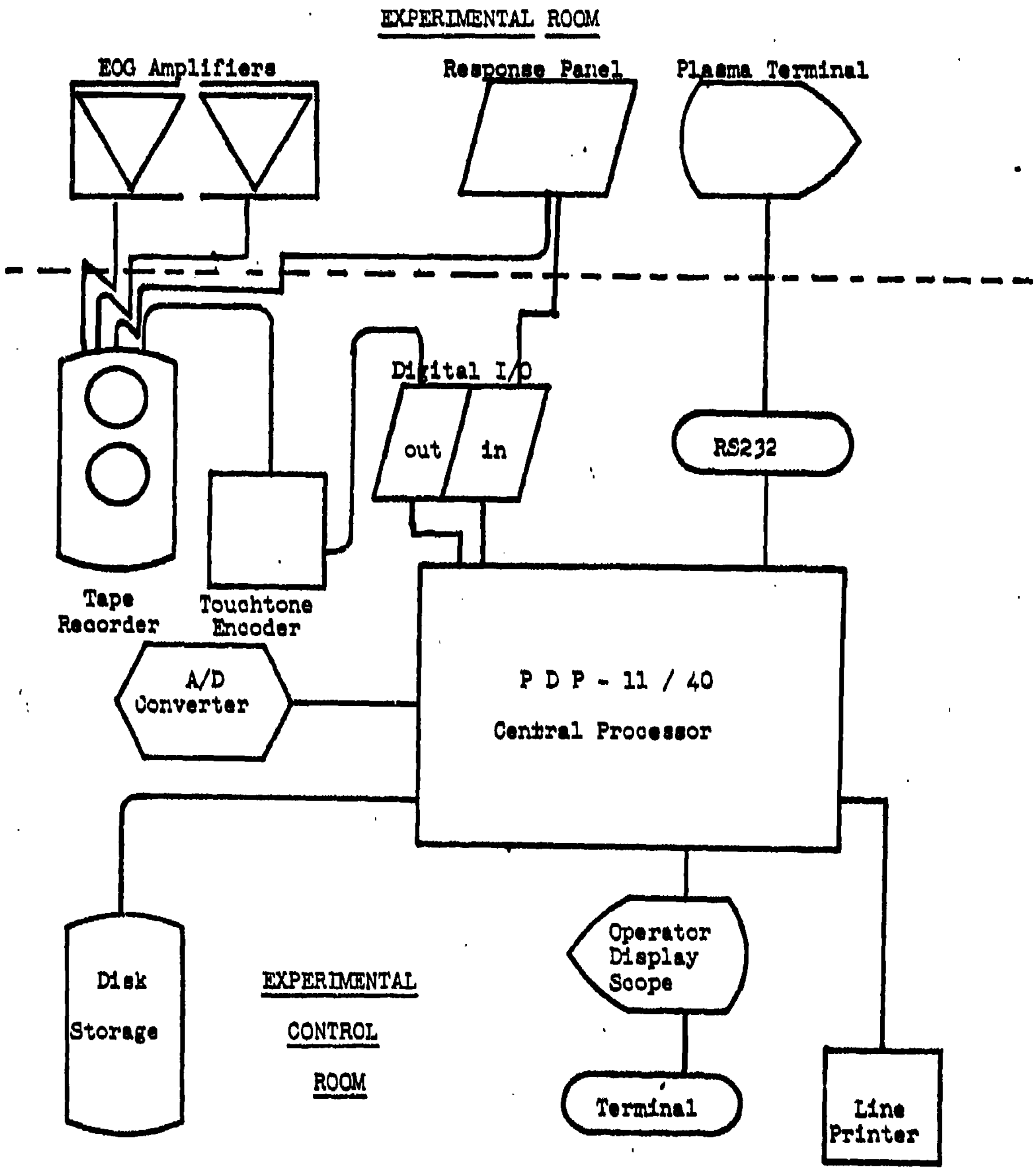

Figure 3. Hardware Configuration.

is the same <u>and</u> the letter is in sequence) otherwise press right, produced very unstable performance. Error rates were high and decision time excessively variable. Asymptotic performance levels were not obtained within 1-1.5 hours. On the other hand, simple categorical rules (e.g. press right for upper case and left for lower case) elicited minimal involvement in the task. Although subjects rapidly became bored there was no apparent falling-off in task performance.

Two subjects were run using the SEQUENCE task, and two using CASE with a change rule for periods of 1 to 1.5 hours. These tasks were readily learned; asymptotic levels of performance were obtained within 80-100 trials. Choice errors declined to about 5% and remained stable. Similarly, median decision time, based on successive 20-trial blocks, although highly variable across subjects, was very stable for each individual subject.

Blink data for these four subjects were analyzed. Three of the four subjects showed increases in median closure duration and window duration from early to late in a one-hour session. There were significant variations in both blink frequency and the proportionate occurrence of long closure duration blinks across the session. As figure 4 indicates, many of the eyeblinks were closely associated with the events of the performance task.

Temporal parameters of the task were also evaluated. The values ultimately selected were a 1.50-3.00 second range for stimulus duration and a 2.00-6.00 second range for interstimulus interval. This provided a 6.25 second average trial duration, or about ten sets of performance measures for each minute on the task. The variability insured continued visual attention to the stimulus display. This pace seemed to provide the maximum number of performance measures without producing a speed-induced behavioral break-down. These particular values are approximately the same as those we have found to be most useful in choice-reaction tasks using other types of visual stimuli.

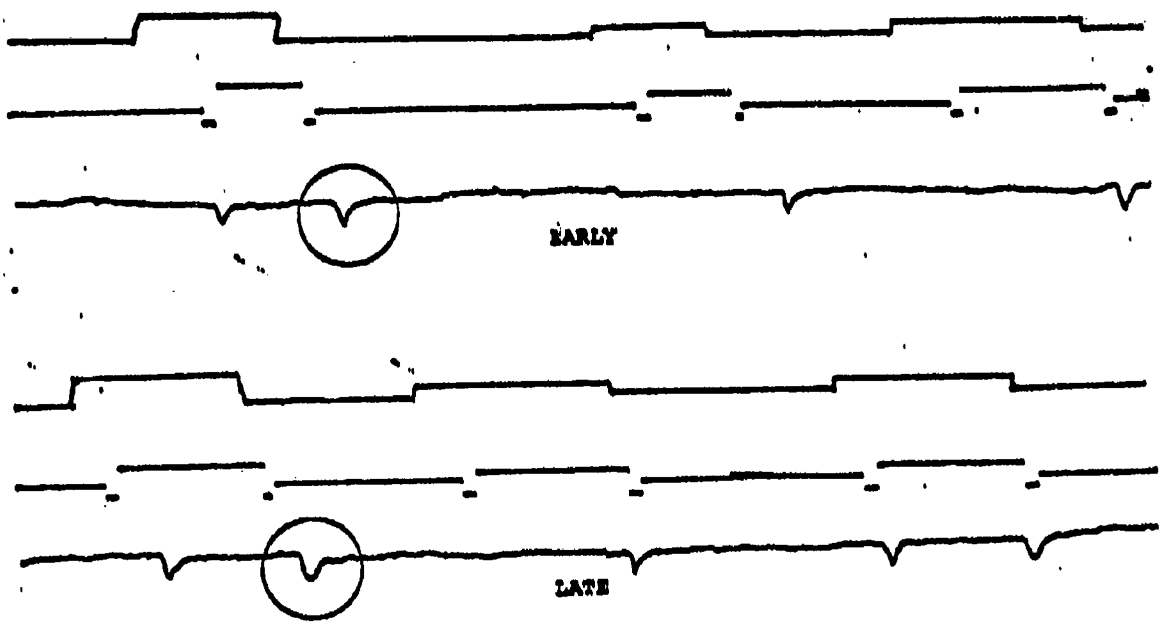

Figure 4. Eyeblink and Motor-response Coordination. Representative polygraph tracings from minute 15 (early) and minute 55 (late) of the information processing, reaction time task. In each instance the top tracing indicates stimulus occurrence, the middle tracing shows the manual responses, and the lower tracing contains the vertical EOG signal. Many of the blinks are closely associated with the motor response. The circled blinks are those illustrated in larger scale in Figure 1 (p. 5). The response channel is shown in greater detail in Figure 2 (p. 22).

C. Experiment 1: Methods and procedure

Data were collected from 16 experimental subjects. All subjects were recruited from the Washington University community; many of them were students. There were 8 males and 8 females, all between 19 and 29 years of age. Four males and four females were assigned to each of two conditions: CASE and SEQUENCE. Subjects were paid a nominal amount in recognition of their participation. Each subject voluntarily signed a standard information and consent form prior to the experimental session. All procedures and requirements of Air Force and the National Institutes of Health pertaining to subject's rights, protection, and safety, were satisfied.

Each experimental run began with an explanation and demonstration of the task. Beckman miniature biopotential electrodes were applied. Vertical electrodes were positioned equidistant from and directly above and below the center of the right eye. Horizontal electrodes were mounted in the horizontal plane through the center of the eyes and approximately 1 cm beyond each outer canthus. A fifth electrode, serving as ground, was applied to the center of the subject's forehead. The skin at each electrode site was cleansed with alcohol and lightly abraided. Standard Beckman electrode gel and masks were used. Subjects were given written copies of the instructions for the task variation to be read during the initial set-up. (Examples of the instructions used are included in Appendix A.) After all questions had been answered and the set-up was complete, there was a period of from 2 to 10 minutes during which the operator insured that all equipment was functional and that the tape recorded signals were adequate.

The first 100 trials were presented in five blocks of 20 trials each. These were designated as training and practice trials. A few subjects gave indication, by excessive errors, that they had not fully understood the instructions. For these subjects, the instructions were repeated between trial blocks, as necessary. At least 8 blocks of 50 trials (for some subjects 2 or 3 blocks of 200 trials) were then administered. The total experimental session lasted 1.5-2 hours. Actual time spent performing the task exceeded 1 hour in every instance.

The program NUALPH was used. Change proportion for CASE was set to 50%. Similarly, the proportion of stimuli not in alphabetical order in the SEQUENCE condition was 50%. The temporal parameters for each trial were those selected in the preliminary study: 1.5-3.0 seconds stimulus duration and 2.0-6.0 inter-stimulus interval.

D. Experiment 1: Reduction and results

Initial analysis of performance measures was based on the abstraction of response information from the on-line record generated by NUALPH. Three 2-minute segments of the record from training and practice trials (designated Practice I, II, and III) were selected for examination. These segments were approximately evenly distributed across the available record for each subject. Three 5-minute segments were also selected from the long runs. These segments designated Early, Middle, and Late), were about minutes 2-7, 33-38, and 62-67 of the long run. Where possible and necessary the exact time period was shifted forward or back by 1 or 2 minutes so as to be entirely within a single block. Where that was not possible, the period between blocks and encompassing the first few trials of the block which began in the middle of the segment were excluded from analysis.

Corresponding segments of the recorded data were submitted to offline analysis. This analysis provided both performance and eyeblink data and also allowed examination of the correspondence between the two sets of responses. On occasion, when very detailed analysis was required, portions of the previously selected segments or other portions of the data were abstracted.

1. Performance measures.

Two general types of errors were identified. Decision errors are those in which the subject moved to the right key when he should have moved to the left, or vice versa. A broader error category, finger timing errors (FTE), consisted of almost all other inappropriate or inaccurate responses. It consisted primarily of 1) responses, such as intertrial tapping or anticipatory responding, which resulted in the subject having his finger removed from the homd pad at the time of stimulus onset and 2) anticipatory returns, either partial or completed, from the response pad to the home pad. As figure 5 indicates, the proportion of trials on which errors occurred decreased throughout practice. This was especially true for decision errors. A portion of the increased accuracy may have been gained at the expense of speed. There is, apparent in figure 6, overall, a small (non-significant) increase in response time. Decision Time Return, however, shows a significant decrease. This component reflects the relatively simple decision that stimulus offset has occurred (i.e. it is in essence simple, rather than choice, reaction time). The combined results from these two sets of measures indicate that learning is progressing throughout the practice trials. This learning involves, in part, a possible speed-accuracy tradeoff to optimize performance. That learning is largely completed at the conclusion of the practice runs is indicated by the absence of any difference in either time-to-respond or errors between practice III and the early portion of the extended trial runs.

Median values for the response time measure did not vary throughout the extended runs. Error rates, however, increased from the early portion to later portions of the task. FTE increased first followed by a later increase in decision errors. The increase in errors, shown in figure 7, corresponds to subject's subjective reports of accumulating fatigue, boredom, and periodic inattentiveness.

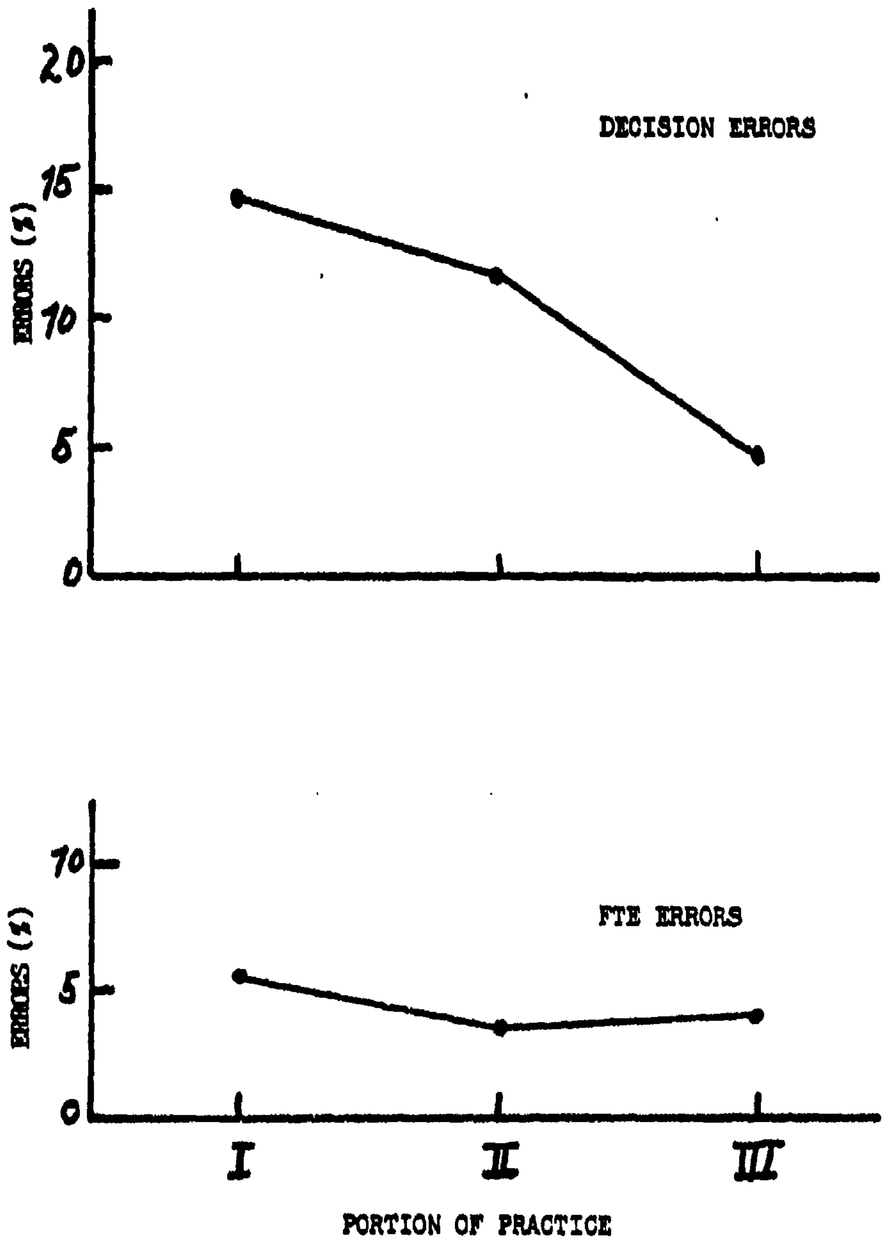

Figure 5. Errors During Practice and Training. Proportion of trials in each of three segments of the practice runs on which errors occured. FTE are "finger timeing errors" consisting primarily of anticipatory responding.

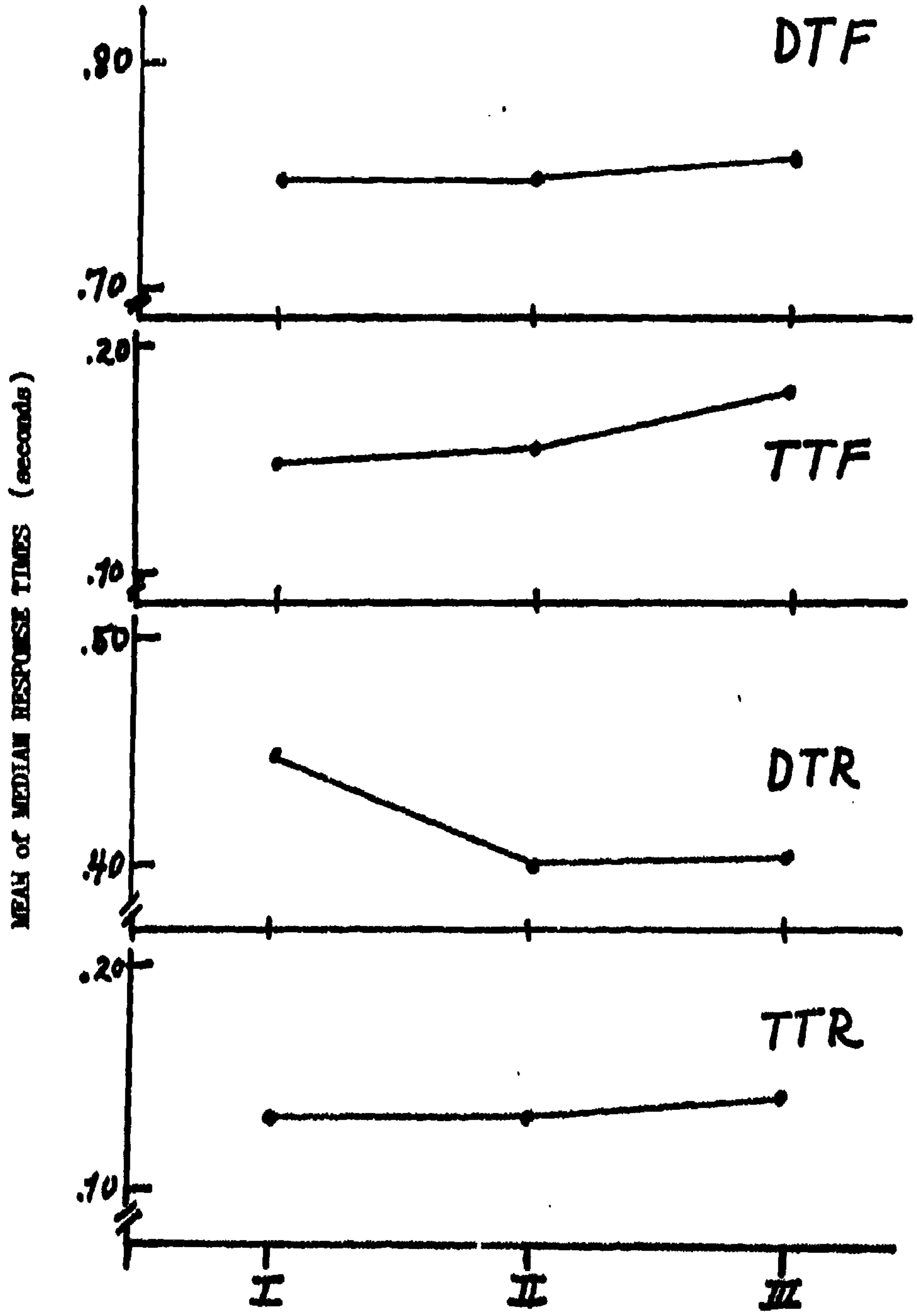

Figure 6. Fractionated Reaction Time during Training and practice. DTF: decision time forward; TTF: transit time forward; DTR: decision time return; TTR: transit time return. See the text for more complete explanation.

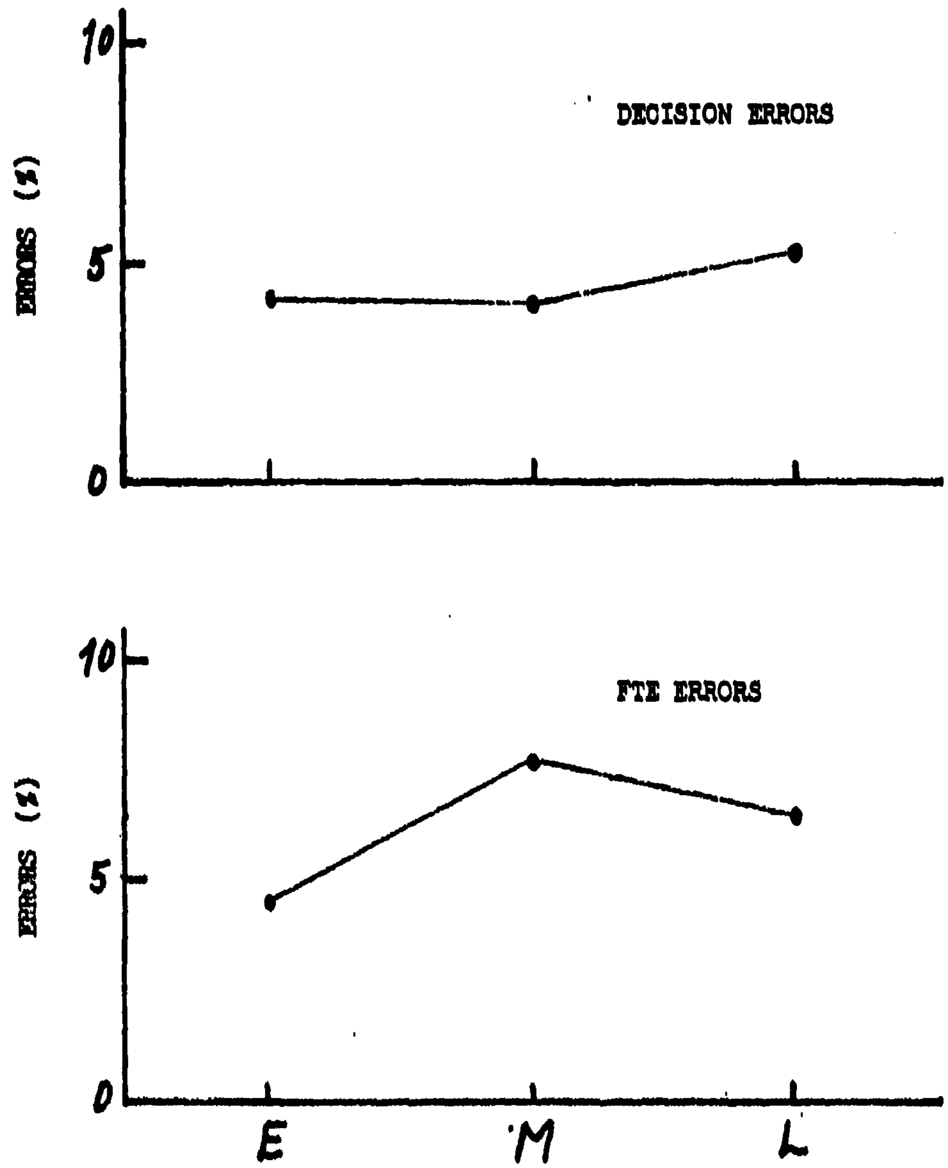

Figure 7. Error Rate on Extended Runs. Proportion of trials from early(E), middle(M), and late(L) portions of the subjects' runs on which errors occurred.

2. Eyeblink measures

As predicted, the parameters of the blink proved sensitive to time-on-task and hence to fatigue or fatigue-like state changes. The consistent increase in blink rate across the entire experimental session was most dramatic. The initial average of 15.7 blinks/minute is close to the rate (14) reported in the literature as average. We have observed, in visual tasks demanding continual attention (i.e. reading), blink rates as low as 3-8 per minute. By comparison the 26.2 blinks/minute average exhibited by the end of the experimental session in the present experiment seems very high. The steady increase in rate throughout the session is illustrated in figure 8.

Both closure duration measures, half amplitude closure and 20% window closure, demonstrated a similar pattern. Each of these measures was analyzed in two ways. First, the median duration was calculated for each subject during each of the six time segments. We expected this measure to reflect tonic changes in alertness. For the second analysis, we determined the proportion of blink which would be characterized as exhibiting long durations. On the basis of the preliminary study, we selected 150 msec as the criterion for a long half-closure duration and 100 msec as the cutoff for long window durations. These data are presented in figures 9 and 10.

3. Eyeblink and manual response coordination

The correspondence between blinks and the choice reaction task, noted in the preliminary studies, was examined more closely. Thirteen of the 16 subjects had sufficiently high blink rate to yield meaningful proportionate data with restricted segments of the session. For each of these 13, comparable 50 blink samples were abstracted from practice II and the early and middle portions of the extended runs. The relationship between time of blink initiation and both stimulus and response events was determined.

In the initial determination, blinks falling between stimulus onset and 1 second after stimulus offset were designated as contingent. This categorization accounted for over 70% of all blinks (see figure 11).

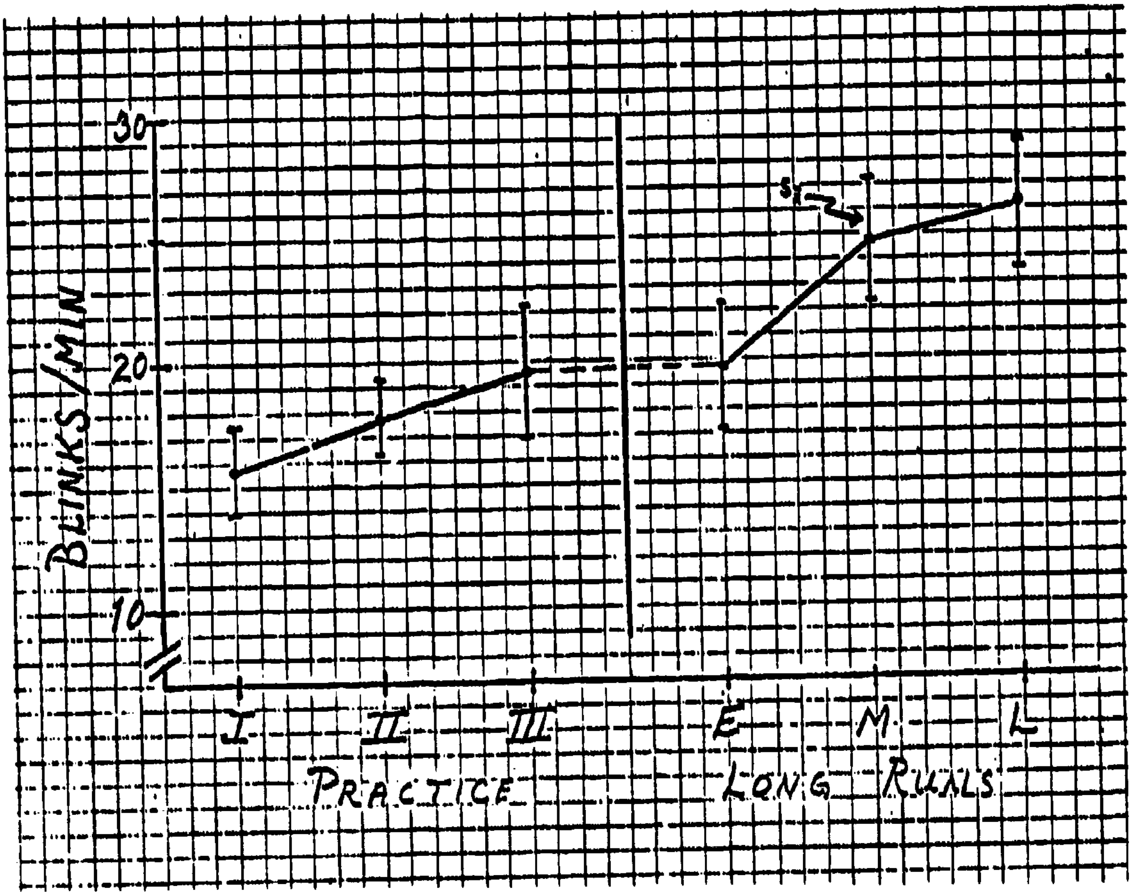

Figure 8. Blink Rate. Changes in average blink rate across the entire experimental session.

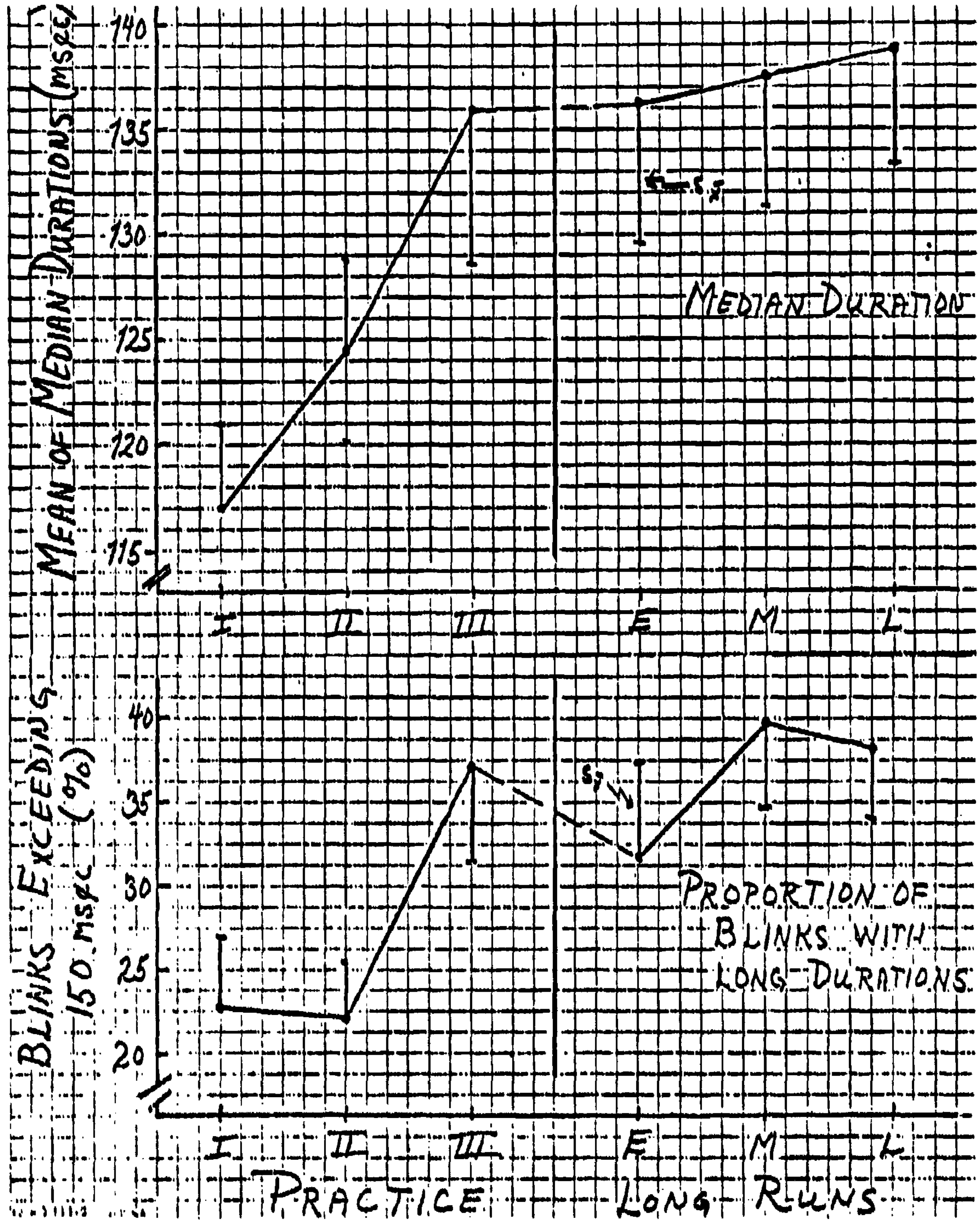

Figure 9. Closure Duration. Increases in median half amplitude closure duration (upper figure) and in proportion of blinks with closure durations in excess of 150 msec (lower figure) across the session.

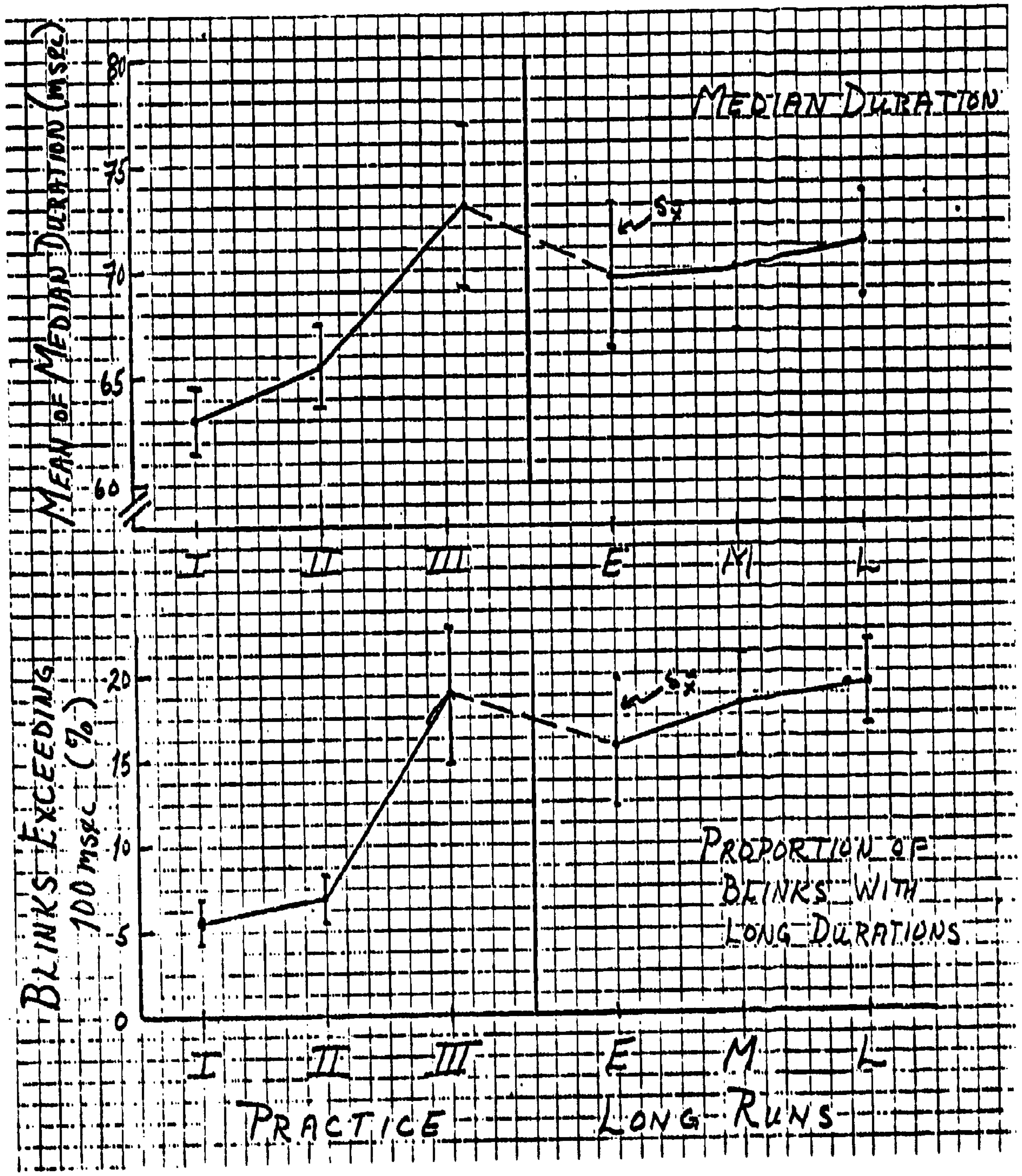

Figure 10. Window Duration. Variation of median 20% window duration (upper figure) and the proportion of blinks with window durations exceeding 100 msec (lower figure) as a function of time within the session.

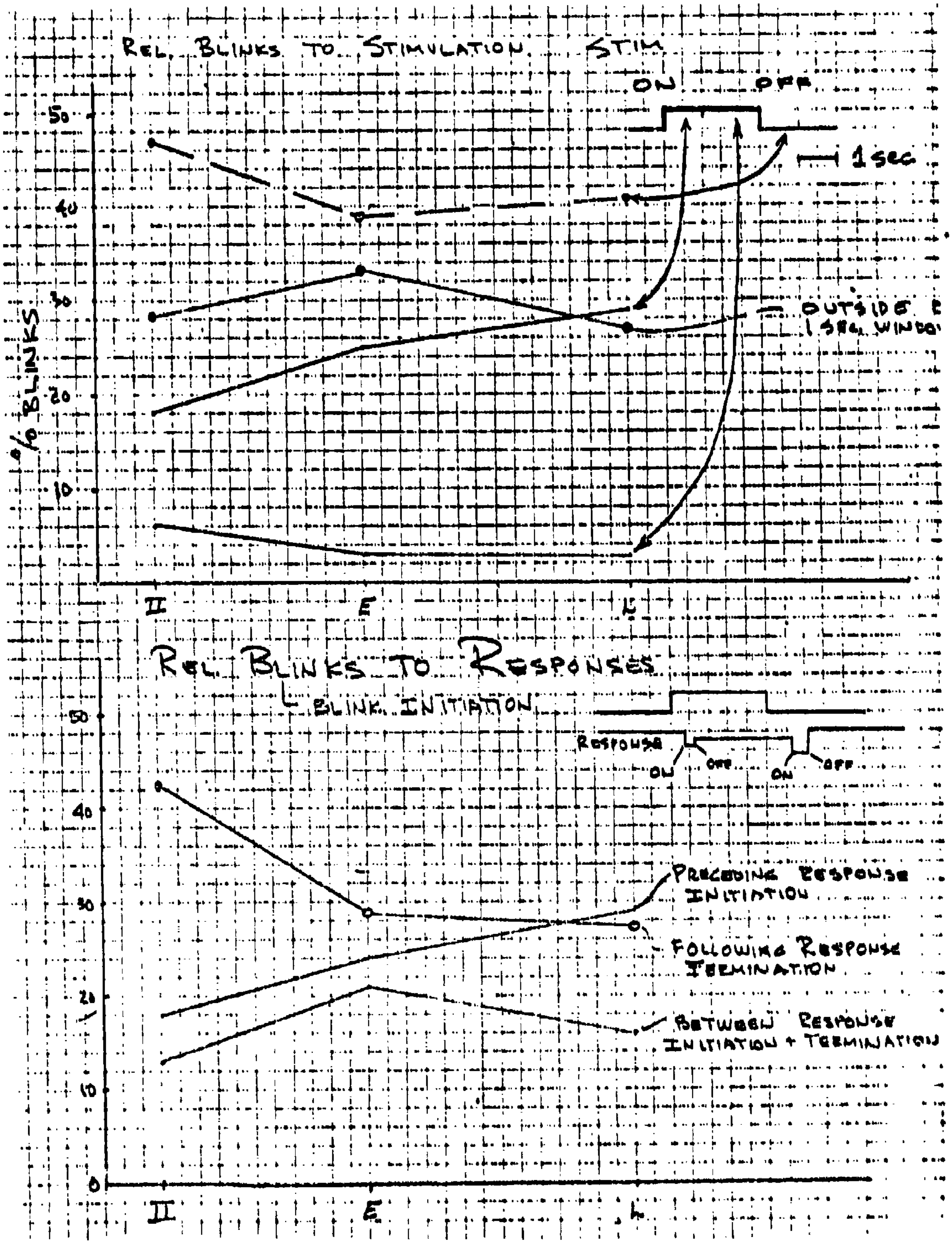

Figure 11. Event Contingent Blinks. The upper portion of the figure shows the proportion of blinks initially identified as contingent. The lower portion shows the relationship between blink initiation and manual response.

A 250 msec window was then constructed around each task event. Sixty percent of the contingent blinks fell with 250 msec of a response. The percentage within this window steadily increased from 55% to 65% across the three time periods sampled. In contrast, slightly less than 25% of the contingent blinks fell within a 250 msec window around the stimulus events.

When the tightness of the time-locking is examined, it becomes clear that the blinks associated with responding are more tightly coupled. As figure 12 shows, a high proportion of the blinks associated with a response were initiated within 100 msec of the response. The same was not true for stimulus associated blinks.

4. Eyeblink and performance measure relationships

We examined performance on trials surrounding trials on which long closure duration blinks occurred. Such a trial was identified as a critical trial. One trial preceeding each critical trial and two trials following it were abstracted. Combining these four trial types and d looking separately at the data for E, M, and L portions of each subject's run produced the data presented in figure 13. DTF and TTR seemed to vary little from segment medians. TTF and DTF, however, tended to be significantly faster than segment medians. Examination of individual trial-types indicates that this effect is primarily due to rapid responding on the trials following the critical trial. There was also a slight, though not significant tendency for DTF to be longer than predicted on critical trials.

Analysis of errors was performed on the individual selected trial types collapsed across segments. FTE were more frequent on trials immediately following critical trials and less frequent on the second trial following critical trials. These FTE included only anticipatory return responses. Decision errors were elevated on the critical trials and to a lesser extent on the trial immediately preceeding it (see figure 14).

It is apparent from these data that alterations in blink parameters,

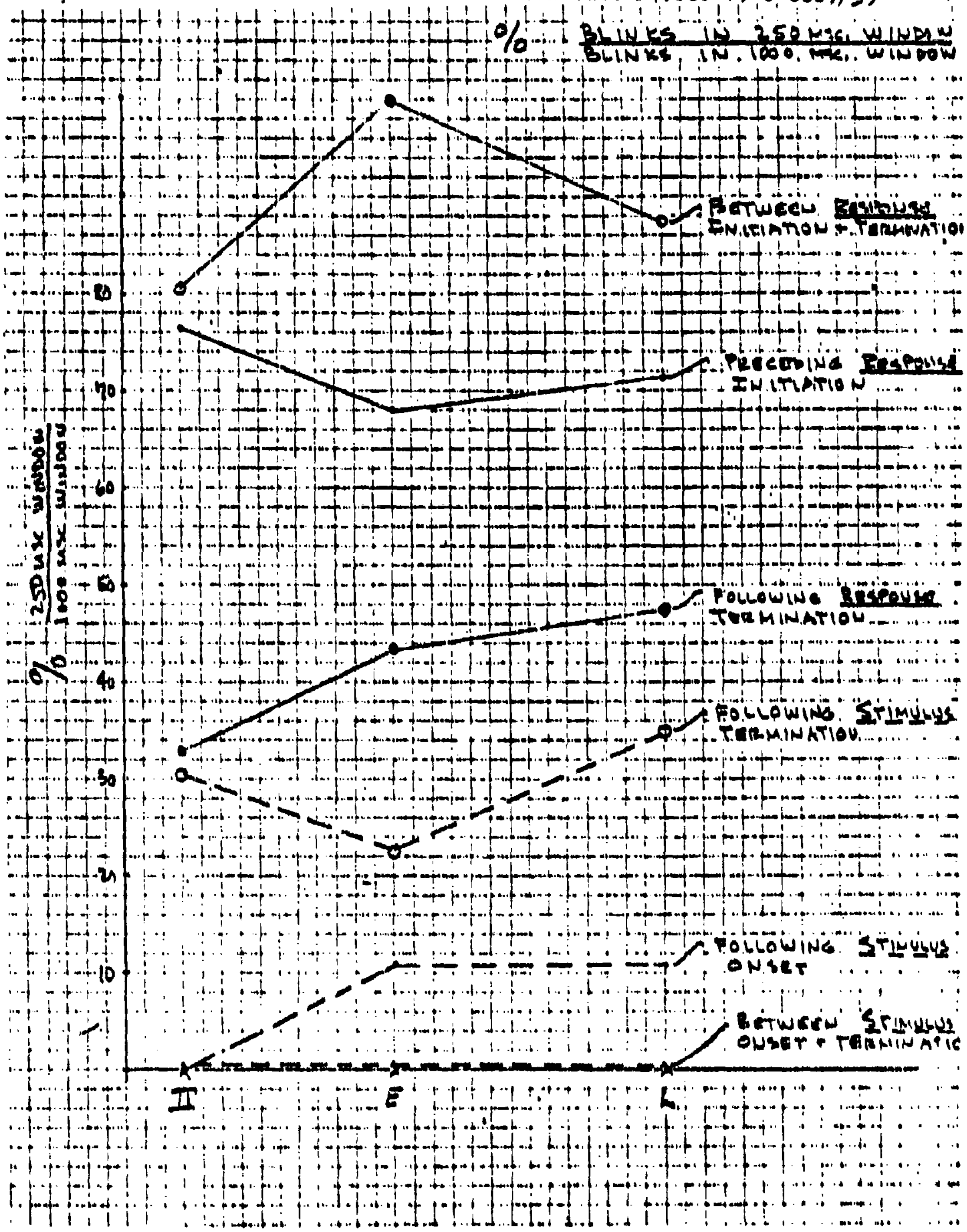

Figure 12. Time-locking of Blinks. The proportion of contingent blinks which occurs within 100 msec of the identified trial event.

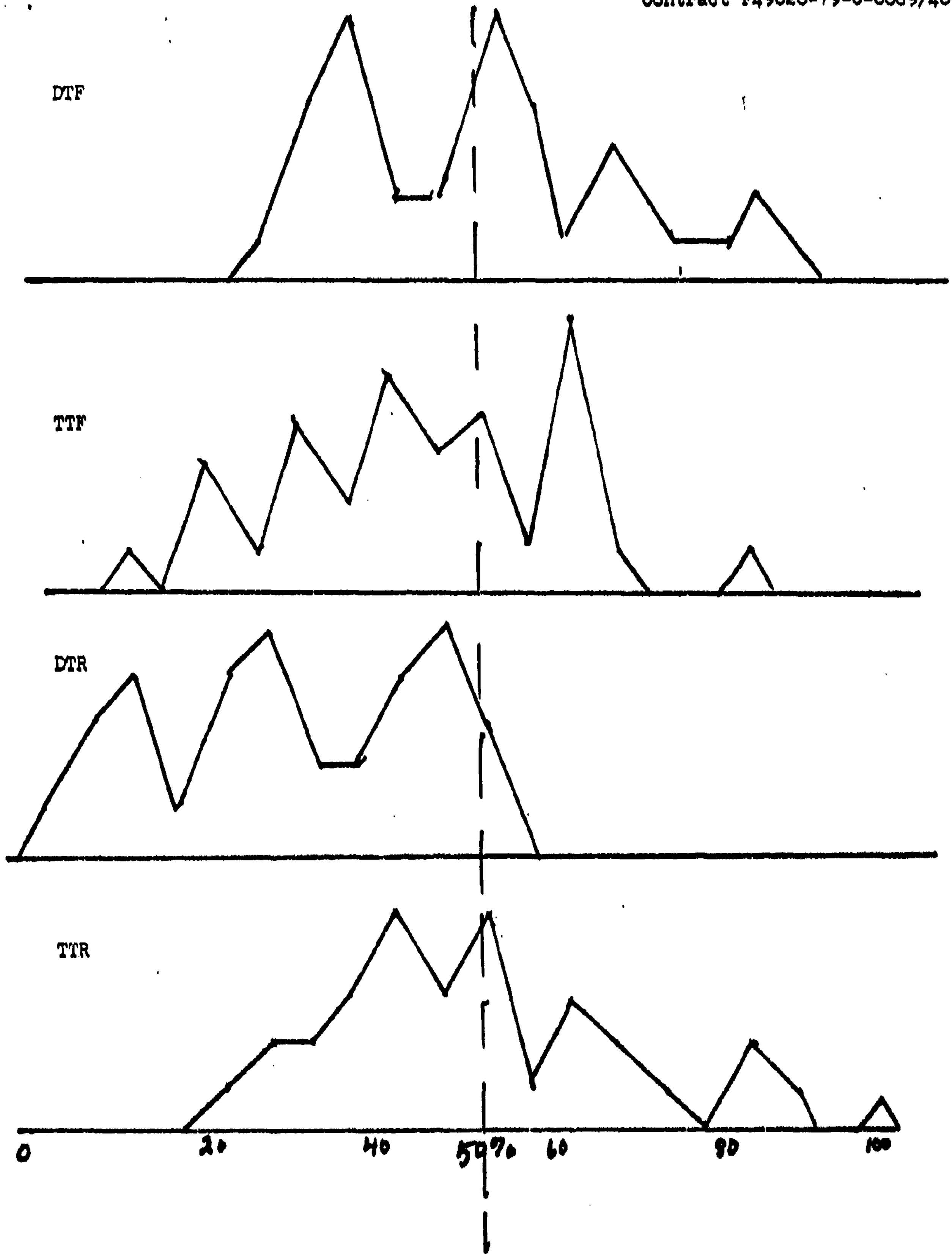

Figure 13. Proportion of trials surrounding long closure duration blinks with response times greater than segment medians.

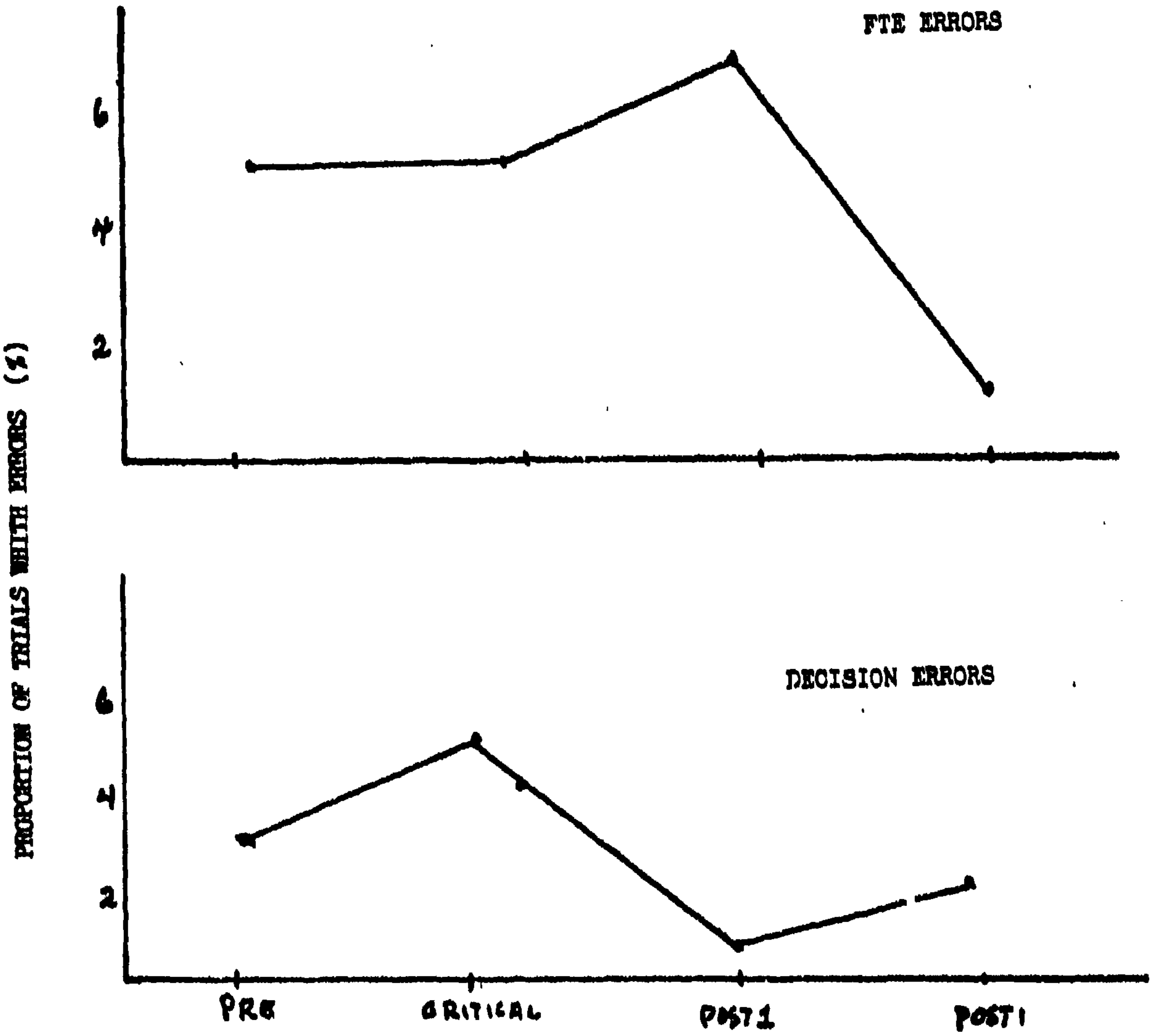

Figure 14. Error rates on trials surrounding those trials on which a long closure duration blink occurred.

i.e., closure duration, is associated with alterations in performance adequacy.

E. Related efforts and studies.

Coincident with the above described experimental work, we pursued software and system developement for study of saccadic eyemovements. Our saccade identification program, which had existed as a stand-alone routine, has been rewritten to interface with the off-line reduction program. Horizontal EOG can be input as a fourth data channel. Saccades are identified and various parameters, duration, amplitude, peak velocity, etc., abstracted for each. This data can be printed out and/or stored on disk for further analysis. Additional analysis and plotting programs have been written to abstract and display in detail the saccade amplitude-velocity relationship.

We also conducted a feasibility study to assess the potential utility of using a microcomputer as a portable real-time system for field use involving oculomoter measures. A summary of that study is included as Appendix B. We have initiated the developement of a prototype system and software developement is in progress.

IV. SUMMARY

In the course of the contract year an experimental task suited to the study of workload factors in the present context has been developed. Eyeblink closure duration was shown to vary in parallel with measures of performance. In particular, performance on trials immediately around trials on which long closure duration blinks occurred demonstrated variations in performance. The oculomoter measures examined effectively reflected both tonic and phasic alterations in state.

SELECTED BIBLIOGRAPHY

Becker, W. & Fuchs, A. F. Further properties of the human saccadic system: Eye movements and correction saccades with and without visual fixation points. Vision Research, 1969, 9, 1247-1258.

Beideman, L. R. & Stern, J. A. Aspects of the eyeblink during simulator driving as a function of alcohol. Human Factors, 1977, 19, 73-77.

Boelhouwer, A. J. W. & Brunia, C. H. M. Blink reflexes and the state of arousal. Journal of Neurology, Neurosurgery and Psychiatry, 1977, 40, 58-63.

Brown, I. D. A comparison of two-subsidiary tasks used to measure fatigue in car drivers. Ergonomics, 1966, 9, 49-56.

Brown, I. D. & Poulton, E. C. Measuring the spare mental capacity of car drivers by a subsidiary task. Ergonomics, 1961, 5, 35-40.

Dichgans, J., Nauck, B. & Wolpert, E. The influence of attention, vigilance and stimulus area on optokinetic and vestibular nystagmus and voluntary saccades. In The oculomotor system and brain functions: Proceedings of the International Colloquium held at Smolenice 19-22 Oct., 1970. Edited by V. Zikmund. Butterworths: London. Publishing House of the Slovak Academy of Sciences, Bratislava, 1973. Pp. 281-294.

Fisher, D. F. Reading and visual search. Memory & Cognition, 1975, 3, 188-196.

Gentles, W. & Llewellyn-Thomas, E. Commentary: Effect of benzodiapines upon saccadic eye movements in man. Clinical Pharmacology and Therapeutics, 1971, 12, 563-574.

Gregory, R. L. Variations in blink rate during non-visual tasks. The Quarterly Journal of Experimental Psychology, 1952, IV. (Part 4)

Hall, R. J. & Cusack, B. L. The measurement of eye behavior: Critical and selected reviews of voluntary eye movement and blinking. U.S. Army Technical Memorandum 18-72, AMCMS--July 1972, Human Engineering Laboratory, Aberdeen Research & Development Center, Aberdeen Proving Ground, Maryland.

Hawley, T. F., Stern, J. A. & Chen, S. C. Computer analysis of eye movements during reading. Reading World, 1974, XIII, 307-317.

Matin, E. Saccadic suppression: A review and an analysis. Psychological Bulletin, 1974, 81, 899-917.

Ron, S., Robinson, D. A. & Skavenski. A. A. Saccades and the quick phase of nystagmus. Vision Research, 1972, 12, 2015-2022.

Stern, J. A. Eye movements, reading and cognition. In J. W. Senders, D. F. Fisher & R. A. Monty (Eds.), Eye movements and the higher psychological functions. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1978.

Stern, J. A., Beideman, L. & Chen, S.C. Effect of alcohol on visual search and motor performance during complex task performance. In M. Horvath (Ed.), Adverse effects of environmental chemicals and psychotropic drugs: Neurophysiological and behavioral tests, V. 2. Elsevier Scientific Publishing Co., Amsterdam: 1976, Pp. 53-68.

Stern, J. A., Bremer, D. A. & McClure, J. Analysis of eye movements and blinks during reading: Effects of Valium. Psychopharmacologia, 1974, 40, 171-175.

Stern, J. A. & Bynum, J. A. Analysis of visual search activity in skilled and novice helicopter pilots. Aerospace Medicine, 1970, 41, 300-308.

Troy, M. E., Chen, S. C. & Stern, J. A. Computer analysis of eye movement patterns during visual search. Aerospace Medicine, 1972, 43, 390-394.

von Cranach, M. et al. Uber einig Bedingungen des Zusammenhanges von Lidschlag und Blickwendung. Psychol. Forsch. 1969, 33, 68-78. (The relationship between gaze movement and eyeblink under various conditions.)

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TASK INSTRUCTIONS: CASE

You are to do the following task:

Letters will appear in the middle of this screen one at a time. You are to compare each letter to the one last seen and make a decision. The letters can be compared in several ways. For this task you are to compare the letters by case. Some are small (lower case) letters; some are capitals (upper case). You are to decide for each letter whether or not it is the same case as the last letter you saw.

So, for example, a lower case "g" following a lower case "a" would be judged "same case". A capital "R" following the small "g" would be judged "different case", and so on for each letter presented.

You will record each decision with your index finger on this touch panel.

The bottom square is "home". Your finger rests there between responses.

You do not respond to the first letter presented in a series, because you do not yet have a letter with which to compare it. For each letter after that, you respond in the following way:

If the letter is the same case as the last letter you saw, quickly move your finger to the top right square. Leave your finger there until the letter goes off the screen. Then move it back to "home" as quickly as you can and watch for the next letter.

If the letter is not the same case as the last letter you saw, touch the top left square. When the letter goes off, return "home" quickly and watch for the next letter.

Remember:

Right: same case

Left: different case

Hold finger on your response until the letter goes off; then return "home".

Try to move with accuracy and speed.

(Any questions? .... Here are some practice trials: ....)

TASK INSTRUCTIONS: SEQUENCE

You are to do the following task:

Letters will appear in the middle of this screen one at a time. You are to compare each letter to the one last seen and make a decision. The letters can be compared in several ways. For this task you are to compare the letters by alphabetical order (sequence). The letters will be presented either in sequence or out of sequence. You are to decide for each letter whether or not it follows next in alphabetical sequence the last letter you saw.

So, for example, "B" following "A" would be judged "in sequence". An "S" following the "B" would be judged "out of sequence", and so on for each letter presented. (When "A" follows "Z" consider it "in sequence".)

You will record each decision with your index finger on this touch panel.

The bottom square is "home". Your finger rests there between responses.

You do not respond to the first letter presented in a series because you do not yet have a letter with which to compare it. For each letter after that, you respond in the following way:

If the letter is in alphabetical sequence with the last letter you saw, quickly move your finger to the top right square. Leave you finger there until the letter goes off the screen. Then move it back "home" as quickly as you can and watch for the next letter.

If the letter is not in alphabetical sequence with the last letter you saw, touch the top left square. When the letter goes off, return "home" quickly and watch for the next letter.

Remember:

Right: next in sequence

Left: out of sequence

Hold your finger on your response until the letter goes off; then return "home".

Try to move with accuracy and speed.

(Any questions? ..... Here are some practice trials: ....)

Todd Carpenter/1

Introduction to the Design Approach of a Microcomputer-Based System

Introduction

Designing a microprocessor/microcomputer-based instrument is a complex task. The des'gner is faced with a multitude of alternatives from which a "best" choice may not be easily definable. I will attempt to delineate these alternatives into three basic categories, however, there are many design approaches which do not properly fit into these categories. The discission will be primarily from a research, as opposed to an industrial, point of view.

The first thing a laboratory or research group must do is to define their intended extent of involvement in the microcomputer world. The range on involvement might be one-half a man-year and up. It would be unrealistic to expect to incorporate a workable microcomputer into a research project in less than six months, and this would only be possible using a limited variety of general purpose systems. On the other hand, there may be no foreseeable upper bound on involvement. In fact, what might start out as a year's commitment could evolve into a major continuing research involvement. Just as easily, however, what starts out as a multi-year effort could end up falling flat on its face without the proper insight. The discussion which follows will hopefully add some light to the subject and point out the major tradeoffs between three design approaches.

Three microcomputer (uC) design approaches

A. The general purpose uC system.

A general purpose uC system is a self-contained, fully operational computer, based around a specific microprocessor (uP). Examples of such systems would be the TRS-80, Apple, PET, and a host of others, generally available off-the-shelf at many locations. They are designed to run programs, usually in BASIC, but often have the ability to be programmed in the particular uP's machine code. Many of these systems have very inexpensive software packages including such useful utilities as an editor/assembler or disk operating system (DOS). A general purpose system possesses very similar qualities to a mini-computer but is generally slower and has less mass storage capacity.

Although there may be other options available, these general purpose systems usually come with a standard keyboard and video terminal or television interface. This limits input/output (I/O) capabilities in their off-the-shelf configuration, but with a variety of widely available interfaces, they can gain most of the power of a minicomputer. A general purpose system usually comes with a slow, analog quality tape storage system which may suffice in many applications. Floppy disk systems are generally available and can make program development considerably easier. Finally, a very useful peripheral is a line printer which can be simply connected to and operated by the general purpose uc system.

B. The dedicated function uC system or single board computer (SBC).

The approach taken with an SBC is that of minimal hardware investment and of dedicated computer operation. If an instrument is desired to be small, portable, and intelligent, an SBC might be a good approach. An SBC can be buried inside of an instrument and can operate as its brains. Once built, though, it is usually restricted to performing its one appointed task forever. A general purpose uc system cannot often be used for these applications because an instrument cannot be built up around them.

SBC's consist of a printed circuit board (PCB) and all components neatly laid out and soldered onto the PCB. There are a wide variety of components available on SBC's, performing different functions, but they all have the following minimums: uP, system clock, RAM, ROM or ROM space, and some type of I/O. They may also have any or all of the following: real time clock, monitor in ROM, video or printer interface, analog input or output modules, or on-board keypads or alphanumeric displays. There is very little standardization in the computer industry, specifying what components an SBC must have or what it must do. Therefore extreme caution must be exhibited in selecting an SBC.

It is important to understand that an SBC usually has no innate intelligence. All of its smarts must come from the user. These computers are designed to run programs usually in machine language, which must be designed, written, tested and debugged by the user. These tasks may not be at all easy to accomplish with the SBC alone. The SBC should be thought of primarily as the target of the completed software and not so much as a tool for software development.

C. The maximum efficiency uC system.

Designing a maximum efficiency uC system requires probably the largest initial expenditure of funds but is the most versatile approach of the three.

What is meant by maximum efficiency is a computer which is specially designed, chip by chip, to have exactly the necessary components and no others. This can usually only be accomplished in a custom design.

In order to be successful in this "from scratch" approach, a microprocessor development system (MDS) becomes a necessity. An MDS is basically a software support device which enables one to develop programs to run on a uP-based instrument or computer. It allows about as much versatility as is possible for writing, assembling, testing, debugging, and storing programs during development. One must keep in mind that it is a software tool and will not solve all the hardware problems associated with designing a custom uc board. For hardware problems there are such things as logic probes, logic analyzers, and oscilloscopes.

An MDS is usually specific to a uP which means that the purchase of an MDS may well restrict use to that same uP in future projects. If the choice is made wisely this should not cause a problem, because manufacturers are beginning to realize that they must support all of the uP they are selling. Some uP have looked promising at their conception but have subsequently faded away; however, there are some industry standards which will almost certainly be around for quite some time to come, with growing support. For instance, the industry leader, Intel, has on the order of one-half of the uP market with its two main uP families, the 8080 and the

8086, 8 and 16 bit processors, respectively. One can be reasonably assured that they will both be long-lived. Motorola is strongly supporting universities with the hopes of raising the next generation of engineers and computer scientists with their crop of uP products.

At any rate the investment in an MDS may be a very wise one if the involvement in uC field is judged to be a long one.

Choices and tradeoffs of the three approaches

Based upon the initial discussion and the existence of One Thousand Dollars ($1,000.00), a general purpose system should be strongly considered as a starting point. It allows for easy training of personnel and supports simple "add-ons". All of the engineering has been done and a researcher can benefit from the advantage of hobby market pricing--a rather rare phenomenon in research. Programming can be done in BASIC and combined with or replaced by machine language at the user's pace. With the existence of real-time clocks, and versatile analog I/O modules, a general purpose system can be surprisingly powerful.

There may, however, be things that are simply not possible with a general purpose system. It is not intended to be built into a dedicated device. It is not intended to be portable (on a day-to-day basis). It may not have exactly the right peripheral or "attachment". In these cases an SBC or custom-designed board might be in order. Keep in mind, however, that an SBC may not have its own monitor and is not programmed in BASIC, and that a custom board will not have numerous available interface boards and peripherals. A custom board will require custom interfaces.

Consider uC development costs. A general purpose system will probably cost upwards of One Thousand Dollars ($1,000.00). This cost may be a significant percentage of the total development cost because the system requires no tinkering. It can be brought into the lab, plugged in, and running programs in an hour.

With an SBC some means for developing programs becomes necessary. The minimum requirement is to have an on-board monitor which allows loading and changing memory locations and executing programs. Programming this way is a terribly tedious process and produces dubious results. Even with a fully operational program, the SBC must have the appropriate I/O capabilities to carry on some meaningful task. An SBC, therefore, will require many times the development effort and cost of a general-purpose system. SBC themselves can range in cost from $100 to $1,000, or more, depending on their performance characteristics.

If on the order of Three Thousand Dollars ($3,000.00) were available for equipment, an MDS in conjunction with a hand-picked (MDS-compatible) SBC might be used. The SBC could supply the engineered and tested, appropriately configured components and the MDS could provide the necessary software support. The result would be a workable combination of hardware and software ending in a dedicated operational SBC and a free MDS ready to take on the next project. The total cost would be the sum of the SBC, a prorated percent of the MDS, and X number of man-hour dollars. In the long run this is an extremely versatile and reasonably cost-effective approach. It should be prefaced, however, with some experienced staff or flexible deadlines.

Summary and recommendations

Deciding how much to invest in a uC system is dependent on interest, present experience, requirements, and time constraints. Relative costs must be placed on initial investments, development time, and versatility.

The areas of software and hardware support must be carefully considered. Either a general purpose system or an MDS with an SBC, alleviate most of the hardware problems and let the user tackle only the software. Developing a uC system with an MDS or SBC alone requires expertise in both hardware and software.

My recommendation would be as follows.

For a laboratory with little or no experience with uC's or uP's, a general purpose system should be examined carefully for its abilities and limitations. If the project requirements are clear and the general purpose system is adequate, then it should be utilized. If the uC is to be used in a dedicated environment, then an SBC may be the most appropriate choice. Software development will become the primary problem and some other support equipment may be necessary for this. An SBC with an on-board monitor would be a minimum requirement. If a custom design was absolutely necessary, then an MDS might be required for extensive software support. The MDS alone, however, would probably not be sufficient for tackling all the hardware problems as well. The custom design approach is the most complicated of the three and requires a good deal of time and experience.